

Considerations for Medical Transport From the Space Station via an Assured Crew Return Vehicle (ACRV)

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Foreword

This document was initially completed and formally presented to the Medical Operations Branch at the Johnson Space Center in December 1989. During the time this document was originally compiled, Philip Stepaniak, M.D., was working as a senior resident in Emergency Medicine at Wright State University under the supervision of Glenn C. Hamilton, M.D. Dr. Stepaniak currently works for NASA in the Medical Sciences Division.

Although in planning for many years, the International Space Station with its continuous human presence has only become a reality this year. This historic event has renewed interest in medical contingencies associated with spaceflight. The following document has existed within and been used by the Medical Operations Branch since 1989, and it has recently been cited in internal documents relating to medical contingency planning and to the medical capabilities of the X-38. Renewed interest in low-Earth orbit medical operations and the potential for extended-duration missions on the horizon has led to it being formally submitted to the NASA Scientific and Technical Information Center for general access.

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Acronyms

ACRV	assured crew return vehicle
BP	blood pressure
CERV	crew emergency return vehicle
CPR	cardiopulmonary resuscitation
CVA	cerebrovascular accident
DCS	decompression sickness
ECG	electrocardiograph
EMT	emergency medical technician
ETT	endotracheal tube
EVA	extravehicular activity
GEU	genitourinary
HEENT	head, eyes, ears, nose, and throat
HIMF	health maintenance facility
IV	intravenous
PASG	pneumatic antishock garment
PEEP	positive-end expiratory pressure
psi	pounds per square inch
SAR	search and rescue
SCRAM	shuttle crew return alternative module

Introduction

On August 25, 1987, representatives of the Department of Emergency Medicine at the Good Samaritan Hospital and Health Center, Dayton, Ohio, outlined their "Considerations for Medical Rescue from Space Station" to a consulting group on the space station crew emergency return vehicle (CERV) and on medical transport. This group was assembled by representatives of NASA at the Johnson Space Center, Houston, Texas. It was chaired by Joe Boyce, M.D., CERV Medical Study Manager at that time for the Medical Operations Branch.

Because of continued interest expressed in this outline by the committee and the CERV Medical Study Manager, a grant proposal was submitted to NASA on January 28, 1988, under the auspices of the Good Samaritan Hospital and Health Center. The proposal requested support to develop the outline into a discussion paper. The paper promised to develop a list of medically important considerations that may influence decisions when designing an assured crew return vehicle (ACRV) and its protocols for operation in medical transport. It was understood that these considerations would not be all-inclusive but would, rather, delineate areas for future discussion and research.

The grant was approved to run for 1 year beginning September 1, 1988. Because of delays related to the primary investigator's sabbatical, a 3-month extension—until December 1, 1989—was granted by the Space and Life Sciences Procurement Branch in September 1989.

Listing of Considerations Under Each Major Heading

1. Background
2. Safety
 - a. A discussion of the cost-to-benefit ratio of the ACRV specific to medical transport is necessary.
 - b. Listing and discussing safety issues for an ill or injured crewmember(s) and the accompanying crew is necessary.
 - c. Safety and medical integrity of the patient during transport must be considered.
3. Assured Crew Return Vehicle Design
 - a. Primary reasons for selecting an ACRV design, discussed in the context of medical transport.
 - b. Secondary reasons for selecting an ACRV design, discussed in the context of medical transport.
4. Equipment
 - a. Function and placement of all physiologic life support equipment in the ACRV should be determined. Capacity of selected equipment to function in microgravity and a +G environment requires assessment.
 - b. Equipment for transporting the patient to the ACRV and securing his/her position in the ACRV should be detailed, including demands on payload capability, ACRV maneuverability, and the position and role of other crewmembers.
5. Indications for Medical Transport
 - a. Decision to transport ill or injured crewmembers includes training of on-site persons who are making the decisions, the resuscitation capability of the health maintenance facility (HMF), the deconditioned status of the patient, the ACRV reentry profile, the severity and natural course of the illness or injury, and the availability of the shuttle for transport. At this time, only limited human experience with prolonged spaceflight can be used for reference in this work.
 - b. The value placed on a crewmember's life or limb is an emotional and a complex point of discussion. Before removing an injured or ill crewmember, the inherent risks and benefits to the patient, crew, and the mission itself must be addressed.
 - c. Various disease possibilities and their evolution in a space station setting require discussion. The major potential disease categories are listed.
6. Transport Protocols
 - a. Coordination between station and ground rescue forces is necessary to seek the optimal window of opportunity for reentry in light of the availability of rescue forces with respect to the space station's position. (See search and rescue (SAR).)
 - b. Preflight patient care protocols need to be developed, including general systems checks and items for specific disease entities.
 - c. In-flight patient care protocols are necessary. If possible, most resuscitation and stabilization will be performed in the HMF as part of the preflight protocol.
 - d. Loading/unloading protocols need to be developed.
7. Transport Complications
 - a. Possibility of crew-related complications during transport must be anticipated.
 - b. Possibility of ACRV-related transport complications must be considered.
8. Search and Rescue
 - a. Time-axis intervention relationship of transport and recovery must be anticipated.
 - b. Range of potential landing sites must be selected. Optional medical response must be identified within the confines of these sites.

c. SAR forces specific to the ACRV must be developed. They should not require significant retraining.

9. Medical Transport Team

- a. Qualifications of medical personnel on board the space transport vehicle should be established.
- b. Qualifications of Earth-based medical transport crew should be established.

10. Other Considerations

- a. Replacement of an ACRV on the station.
- b. Several medical issues require review and clarity, including health insurance, medical/legal issues, and the need for extended care.
- c. Although many issues that involve decisions for medical transport, the means of transport, and the physiologic response and outcome of various diseases to reentry and recovery are unknown, they are as critical as supporting those issues that involve the engineering and mechanical aspects of the space station and the ACRV.

Background

In the development of a permanently crewed space station, the importance of medical care has been continually reaffirmed. The HMF is an integral component of the station. It has diagnostic, therapeutic, monitoring, and information management capability. It is designed to allow supportive care for:

1. Most non-life-threatening (Class I) illnesses; e.g., headache, lacerations.
2. Most moderate to severe, possibly life-threatening (Class II) illnesses; e.g., appendicitis, kidney stones.
3. Severe, incapacitating, life-threatening (Class III) illnesses; e.g., major trauma, toxic exposure.

Since the HMF is not anticipated to have a general surgical capability, and since the variety of significant hazards increases with prolonged stays in space, the need for emergency escape and recovery methods has been seriously studied. A number of reports within NASA and from consulting committees have supported the development of a CERV—a unit more recently known as an ACRV.

Medical risk assessments have determined that accurate prediction of the incidence of crewmember illness/injury on the space station is impossible. Epidemiologic data is of little use because of inaccuracies in extrapolation. A best estimate of a significant illness/injury rate is 1:3 per work-year, with 1% of these predicted to need an ACRV. For an eight-person crew, this means that one ACRV will be used every 4 to 12 years.

The ACRV has been seen as a multipurpose unit since its inception. As such, it would serve at least three basic objectives as:

1. A crew return if the space shuttle is unavailable.
2. An escape vehicle from a major time-critical space station emergency.
3. A full or partial crew return vehicle for a medical emergency.

The focus of this paper is the third objective for the ACRV. Although the frequency and severity of illness and injury in American space crews has been relatively low, it is understood that longer periods in space increase the risk of serious problems. This is corroborated by the Soviet space station experience of the mid-1980's in which at least three cosmonauts returned under relatively "urgent" conditions for medical reasons. (Serious trauma had not played a major role in their illnesses.)

The space shuttle may be used as part of the recovery force for space station evacuation since it has numerous advantages for transporting a crewmember who requires medical attention. But, an unscheduled rescue attempt by the shuttle would cost approximately \$200M and, depending on weather conditions and the status of the fleet, could require as many as 15 to 45 days to effect. This may be an unacceptably long delay for a critically ill crewmember or if immediate evacuation of the station is necessary. Finally, the shuttle requires highly trained onboard personnel to operate it safely. We therefore believe it is necessary to consider alternative means to using the shuttle to return space station personnel safely and quickly to Earth.

While they were designing a study for NASA on the cardiopulmonary effects of +Gx reentry profiles in a hemorrhagic shock model, physicians from the Department of Emergency Medicine at the Good Samaritan Hospital and Health Center in Dayton, Ohio, became interested in the issues and decisions involving the ACRV as a medical transport unit. Their initial work, which focused on when the ACRV might be used and on injured patient tolerances for reentry +Gx profiles, expanded into a list of considerations important to the timely and safe transportation and recovery of one or more crewmembers from the space station to Earth.

This paper, which has received NASA's support, is an expanded discussion of these considerations from a medical perspective. It is not meant to be all-inclusive. Instead it represents the most important elements of planning for the effective return and recovery of an ill or injured space station crewmember.

Safety

Safety, an inherent goal of any medical rescue in a hazardous environment, is not only the moral responsibility of the operational planning process; it is an economic motivator. All decisions regarding safety require the inclusion of cost/benefit factors. This is more important when the terms "economic" and "cost" are defined in the broadest possible terms to include not only money, loss of work, and death but public image, morale, and political impact. The station ACRV will operate in an environment filled with significant risk. Safety can be best defined and implemented by maintaining an economic incentive to keep costs down.

CONSIDERATION 1: The cost-to-benefit ratio of the ACRV specific to medical transport must be discussed.

Facts/Comments

The importance of medical transport as an ACRV objective has steadily gained support within NASA. It now has a level of importance similar to crew return if the space shuttle is unavailable, or to providing escape from a major time-critical space station emergency. Because of the importance of medical transport, the following points are best discussed in a document specific to the issue of safety.

1. Cost
 - a. Actual cost in terms of money, time, and resources of ACRV construction, launch, assembly, maintenance, and replacement (if used). Cost will be calculated after the ACRV basic configuration has been decided.
 - b. Moral/psychological expense on personnel of not having a medical contingency transport system.
 - c. Media expense of having/not having a medical contingency transport system before, during, and after such a system is actually required.
 - d. Political expense, in regard to present and future funding, for having/not having a medical contingency transport system before, during, and after such a system is actually required.
 - e. Real potential cost of loss of life or limb should illness or injuries occur in space with or without a medical transport system available.
2. Benefit
 - a. Cost savings of constructing, maintaining, and replacing an ACRV with different configurations. The unit must have reasonably flexible capabilities that match the projected needs of medical transport, but it is not meant to be all things for all possibilities.
 - b. Cost savings of using existing engineering technology, materials, and equipment in the design and instrumentation of the ACRV. For example: Can standard resuscitation equipment be reasonably modified to serve the needs of an ACRV?
 - c. Moral, morale, media, and political benefits of subscribing to the safety-oriented image that has always been part of planning at NASA.
 - d. Real benefit of saving life and limb with an ACRV.
 - e. Scientific benefit from translating real experience back to the laboratory.

CONSIDERATION 2: Listing and discussing safety issues for the ill or injured crewmember and accompanying crew is necessary.

Facts/Comments

The patient is not expected to administer self-care. During transport, because of relatively short transit times and gravity forces anticipated to exceed 3 Gx, the patient's fellow crewmembers will have little or no opportunity to deliver care. The patient must therefore be secured and protected prior to placement in the ACRV. Once in the ACRV, the following elements must be considered:

- a. Movement – Protection in all directions is necessary. The transport device (i.e., stretcher) from the HMF to the ACRV will optimally become an integral and secure part of ACRV transport. Appropriate padding and straps for securing the patient and for splinting injured extremities, including the spine, are necessary.
- b. Pressure/Temperature Extremes – The patient’s thermoregulatory and cardiopulmonary capacity is likely to be compromised. Since it is unlikely he/she can be placed in an environmentally controlled suit or a “mini-capsule,” the ACRV should serve as an environmentally controlled space.
- c. Noise – Standard precautions for noise reduction and protection during reentry are to be incorporated into the ACRV design.
- d. Inhalation of Toxic Fumes – Precautions for maintaining clean air standards are part of the ACRV. These include the situation in which a patient may have materials remaining on his/her skin or in the body that may be toxic to other crewmembers.
- e. Radiation – Protection from exposure to external radiation is part of the ACRV safety requirements. Handling of radiation exposure inside space station would be managed by a protocol in the HMF prior to ACRV transport. Ingestion or inhalation of radioactive material would not preclude ACRV transport.

CONSIDERATION 3: The patient’s safety and medical integrity must be considered during transport.

Facts/Comments

A patient’s medical stability is maintained, as much as possible, prior to ACRV transport. Minimally, equipment, protocols, and training must operate at advanced life support levels. Essentially all or most of this work must be done pre-transport—either in the HMF or immediately prior to departure in the ACRV.

Physiologic requirements for patient stabilization include:

- a. A patent and protected airway.
- b. Adequate oxygenation and ventilation.
- c. Intravascular access.
- d. Volume resuscitation.
- e. Effective oxygen-carrying capacity; i.e. adequately functioning levels of hemoglobin or oxygen-carrying substitute.
- f. Spinal and extremity immobilization.
- g. Cardiac homeostasis, including dysrhythmia prevention and adequate cardiac output.
- h. Pain relief as needed. Sedation, secondarily, may also be needed.
- i. Medications (primarily standard resuscitative medications) as needed.
- j. An awareness of physical/psychological comfort and relief to be given to the degree available.

Basic physiologic parameter monitoring needs to be available to assess the effectiveness of resuscitative efforts and the evolution of the illness/injury over time. Parameters include:

- a. Blood pressure.
- b. Heart rate and rhythm.
- c. Respiratory rate.
- d. Oxygen saturation of blood by oximetry.
- e. Level of consciousness.

Summary

By translating safety into an economic factor, cost-to-benefit considerations can be discussed in a realistic manner. The concept of “cost” must be broadly defined. Specific safety issues must be included in the design and equipage of the ACRV. Early inclusion of these medical concerns will not preclude ACRV use for other objectives.

Assured Crew Return Vehicle Design

Various vehicles are candidates for the ACRV mission⁽¹⁾. Among these is the Langley lifting body, a winged vehicle that can fly reentries with low-gravity loads. The loads for the Langley vehicle would be only 1 to 2 G's. It could also return crewmembers to a more specific range of landing sites. The disadvantage to the Langley vehicle is its added cost and complexity compared to that of a capsule designed for water landings. And, a winged vehicle such as the Langley vehicle may be considered more sophisticated than necessary to satisfy the medical transport objective.

An Apollo-derived configuration could provide a return to Earth with moderate gravity loads due to the lift generated by the aerodynamic design. The vehicle would have loads of 2.5 to 3.5 G's. The capsule would descend by parachute to a water landing. Advantages to its use are that the design is similar to the generic concepts of the Apollo spacecraft, it is well understood, and it is less expensive than the winged vehicle. Disadvantages to its use include an operational pressure of 5 psi (compared with 14.7 psi for the space station), a complex interface with the station, and the time delay potential of a water recovery.

The ballistic capsule design (reference configuration), which is shaped like the earlier Discover Program vehicles, would cost least to develop. It has an extensive database from uncrewed flight experience and would have limited controls matching its flying characteristics. Problems with its design include acceleration loads of up to 7 to 8 G's during reentry and the fact that a vehicle of its planned size has not flown yet.

Although a fourth configuration, the shuttle crew return alternative module (SCRAM), is also being investigated, it is not considered viable for medical transport because of its reentry profile, limited capabilities, and high potential for extended crew rescue waiting time.

CONSIDERATION 4: The primary reasons for selecting an ACRV design should be discussed in the context of medical transport.

Facts/Comments

The design goal of the ACRV is to provide a transport and life support vehicle for a single mission event. Optimally, little or no new or inventive technology will be required. The challenge is to maintain balance between an effective crew return capability and the lowest practical life cycle cost⁽²⁾.

In designing a vehicle for medical transport from the space station, various factors must be considered to ensure the overall safety of the injured/ill crewmember and of transport personnel. Primary considerations include the crewmember's tolerance to reentry, rotation, and impact forces⁽³⁾.

Design and G-forces (reentry, rotational, and impact)

Human resistance to acceleration forces depends on a number of physical, environmental, and physiologic factors. Significant physical factors include magnitude, duration, and direction of the force; position of the body and extremities in relation to the force; and whether that force is applied in a "plateau" or a "peak" mode. Environmental factors include the use of protective systems and body restraints and environmental conditions—e.g., temperature, pressure. Individual human tolerance, one of the most important factors, varies with the health, age, training, and individual motivation. An ill or injured patient is likely to be less tolerant of these forces. The physiologic tolerance of acceleration in humans is determined by (1) interference with normal hemodynamic relationships, (2) mechanical impedance of respiration, and (3) displacement and deformation of internal organs.

Studies have shown that the +Gx direction (chest to back) is the optimal axis for acceleration tolerance of humans in spacecraft since it results in less severe hemodynamic changes. Chest pain, visual disorders, petechial hemorrhage, and dyspnea are the usual limiting factors in voluntary +Gx exposure up to 10 G's.

Previous experience with medical transport has shown certain illnesses are worsened by acceleration in any axis. These illnesses involve high patient risk during transport regardless of the vehicle, including the use of C-9 medical aircraft and helicopters.

Some patients suffering illnesses such as acute psychotic reactions, kidney stones, and some burns could be transported with reentry forces of up to 8 to 11 Gx without incurring excessive danger. However, the majority of ill patients cannot tolerate high 8 to 11 +Gx axis load levels without worsening due to hemoglobin saturation decreases; detrimental gravity-induced fluid shifts; mechanical distortion during high gravity; and gravity-force effects on their cardiovascular and other body systems. Indeed, a number of critical medical/surgical illnesses could worsen to an

unacceptable degree. The patient's tolerance would be affected significantly by the degree of pre-transport resuscitation available.

Data on hemorrhagic shock and Gx acceleration supplied by Wright State University and Armstrong Aerospace Medial Research Laboratory, combined with knowledge of acceleration effects on normal subjects, may assist in predicting a variety of traumatic and cardiovascular disorders suitable for transport on an ACRV depending on reentry profiles. Medical research on the effects of varying gravity-load profiles on ill or injured crewmembers should continue to determine the safe range of reentry profiles in the context of potential illnesses, pre- and post-resuscitation.

Spin stabilization, while helpful in guidance and control, may harm crewmembers in an ACRV. While spin rates of less than 5 to 8 RPM may be well tolerated in any axis by a healthy person, greater rates may lead to nausea, vomiting, and disorientation in an unhealthy person, depending on axis of rotation. X-axis roll is generally not as well-defined as Z- and Y-axis roll. Though healthy trained subjects may tolerate high RPM in the Z axis (ice skaters revolve up to 400 times/minute) and Y-axis pitch rotation about specific points may be tolerated up to 150 RPM without permanent harm, the mixed vector X-axis roll tolerance of capsule spin stabilization will be markedly lower.

Deconditioned station crewmembers will be especially susceptible to rotational effects because of several factors, including lack of similar vestibular cues during spaceflight and relative volume depletion. Ill crewmembers would almost always be unable to tolerate spin stabilization of more than 5 to 10 RPM.

Human tolerance to impact acceleration is fairly high for extremely brief periods of time (more than 0.2 second). Primate model studies demonstrate an unrestrained lethal threshold of 20 Gx that increases to more than 60 Gx when a primate is restrained properly. Human studies show that up to 50 +Gx may be tolerable for extremely brief periods (0.2 second) with optimal seat and restraint configuration. Persons who are ill or injured may need additional protection from impact acceleration. One method for protecting an injured or ill crewmember might be an impact-attenuating seat that's been designed for transport.

Cabin Space/Entry Configurations

Other primary considerations in developing a medical transport vehicle include the availability of cabin space and the positioning of access doors for crewmember ingress/egress. The amount of care a crewmember will require during transport will determine the number of support personnel required to render that care and the amount of equipment needed. Patients who continuously use a ventilator and a monitoring system will require more space. Proper ingress/egress of that crewmember in making the transition from microgravity to a 1-G environment will determine the positioning, width, weight, and height of the access door. Also, the proper handling and familiarity with the access doors in both the microgravity and the 1-G environment will prevent damage and expedite loading and unloading protocols.

Payload Placement Effects

Another primary concern is the effect of placing and orienting a crewmember, combined with additional equipment, on the center of gravity of the vehicle. Consideration should be given to the importance of loading and unloading with the proper distribution of weight as well as to the effect on the safe operations of the vehicle during reentry, landing, and recovery.

CONSIDERATION 5: Secondary reasons for selecting an ACRV design should be discussed in the context of medical transport.

Facts/Comments

Secondary considerations in designing an ACRV to be used for medical transport include climate control, pressurization, oxygen supply, electrical supply, communications capability and rescue/escape appliances, ease of maintenance during infrequent use, ease of use when needed, and separation and guidance systems.

Climate control or the ability to heat or cool the cabin may require various degrees of sophistication. Consideration must be given to making the ill/injured crewmember comfortable for possible prolonged loiter times in space or for prolonged recovery times after reentry.

ACRV pressurization may be the single most important consideration in making a decision to transport an injured/ill crewmember. The maximum altitude at which crewmembers can fly without supplementary oxygen is 10,000 feet. An injured crewmember may need supplementary oxygen at a much lower altitude, however, and may

be suffering from cardiopulmonary insufficiency, hypovolemia, etc., any of which can be adversely affected by a decrease in atmospheric pressure. The lower pressures found in the Apollo and ballistic vehicle designs would be inadequate for transporting an ill crewmember. A "flight suit," 14.7-psi environment during loiter, reentry, landing, and recovery would provide the most adequate and optimum medical care. Pressure suits may be impossible to wear because of an intravenous (IV) line, a splint or spinal immobilization device, or an endotracheal tube (ETT).

An adequate oxygen supply, one provided by liquid oxygen or by an onboard oxygen-generating system, will be needed for the respiratory equipment. A problem to consider should a ventilator be required is excess oxygen buildup in a small cabin space. Buildup from expired 100% oxygen must be prevented to decrease the risk of fire. The design vehicle will need an electrical harness to allow access to outlets for monitors and respiratory and suction equipment. If electrical power is lost when the vehicle is shut down, batteries of sufficient capacity will be required. Also, electrical equipment carried in the vehicle must not generate electrical magnetic interference because it may interfere with the operation of essential navigation equipment.

A sophisticated communications capability is a necessity to efficiently transfer an ill crewmember. Radio voice communication to recovery forces after the ACRV separates from the station would improve rescue capability with minimal delays, maximum safety, and the reassurance of the ACRV crew.

Any vehicle expected to land in water during SAR will need to carry sufficient lifesaving equipment for everyone on board. If minimum equipment is carried, survival will depend on rapidly locating and retrieving crewmembers.

Because of an estimated usage frequency of once every 4 to 12 years, maintenance and ease of use when needed are important topics. The latter is pertinent in medical transport since the time may be short and more than one crewmember may be ill or injured. This situation is also closely tied to the need for both automatic and manual separation and guidance systems. The desire to crew the station as completely as possible when ACRV is necessary, and the possibility of multiple crew problems, make automatic separation and guidance important.

Summary

From a medical contingency perspective, the ideal ACRV design is a winged vehicle such as the Langley lifting body vehicle. This vehicle has the lowest entry gravity profile, and it can land at preselected runway sites that are presumably close to definitive medical care facilities. Unfortunately, it is also the most expensive option.

The least desirable vehicle for a medical contingency would be a minimally controlled ballistic-type vehicle. In its present design, this vehicle has many potentially medically hazardous design characteristics. Among these are poor spin stabilization, high entry gravity profile, insufficient life support for loiter, and inadequate clothing/protective gear. A ballistic-type vehicle is thus considered unacceptable for medical transport.

The Apollo-derived design, while not ideal, can supply some capabilities for ACRV use. The vehicle, with its 3- to 4-G entry profile, would be acceptable for many but not all medical contingencies. Its size should accommodate at least six persons, and it can be a compromise choice to serve as a medical rescue vehicle.

The environmental control and life support systems should be a "flight suit," 14.7-psi atmosphere. Further requirements for injured/ill crewmembers should also be available; i.e. oxygen, medical equipment, survival gear.

Overall, the proposed ACRV should not expose healthy or injured crewmembers to more than a moderate level of risk. The ACRV should be capable of accommodating more than one injured or ill crewmember. And, the ACRV will need to provide stowage space for specific medical equipment and supplies.

References

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- ⁽²⁾ Assured Crew Return Capability (ACRC). Phase A report. NASA/JSC ACRV Office 1A13. Houston, Texas: 1988.
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Equipment

A variety of equipment will be transported with the patient in the ACRV. A redundant module with several capabilities, or a module that has been assembled piecemeal to match the medical requirements of the patient, may be secured there. In either case, an underlying objective is to identify existing systems and to modify them rather than to design completely new equipment.

CONSIDERATION 6: The function and placement of all physiologic life-support equipment in the ACRV should be determined. The capacity of selected equipment to function in a microgravity and +G-environment will require assessment.

Facts/Comments

All physiologic life-support equipment must be selected to meet appropriate specifications of size, weight, battery life, power availability, tolerance of microgravity and high-gravity environments, and levels of electromagnetic interference. Equipment should be portable to provide, at the point of injury or illness, the capability for use throughout the station to the HMF or ACRV. Some portable items of duplicate equipment from the HMF might be carried to the ACRV. The ACRV may contain some dedicated equipment, either portable or installed.

Airway Protection/Supplemental Oxygen

Airway adjuncts, if needed, most likely will be placed while the patient is in the HMF. In some circumstances—when immediate patient transport is required, a damaged station with an unusable HMF must be evacuated, or an unforeseen airway obstruction or respiratory arrest occurs during in-space loiter or prior to rescue and post-splashdown—supplemental airway devices could be needed on board the ACRV. In this case, standard ETTs placed by laryngoscopy are preferred. Depending on the medical attendant's training and experience, a blindly placed airway device such as a tracheal lumen airway might also be considered. It will be necessary to establish methods and secure materials to prevent airway movement during reentry.

Supplemental oxygen is an essential component of emergency patient care. As well as satisfying the oxygen requirements of uninjured crewmembers, equipment must be available to supplement the inspired oxygen concentrations of injured personnel to achieve elevated blood oxygen concentrations. If an ETT is unnecessary or cannot be placed, a tightly fitting aviation-style mask could be used instead. This would reduce the potential fire risks associated with oxygen leaks from nasal prongs or standard medical oxygen masks. Leakage is not likely to occur when the patient is endotracheally intubated. The presence of aviator-style face masks for all crew positions would allow supplemental oxygenation to treat smoke or toxic fume inhalation and would also increase survivability during a purge of the ACRV's atmosphere following an evacuation that is associated with a toxic leak or fire.

Liquid oxygen must be transformed from its stored state to a room temperature gas. An onboard oxygen generator could be used to concentrate excess atmospheric oxygen and to store the excess oxygen in the supply tank. Administration device selection also depends upon vehicle pressurization, since standard medical administration equipment such as nasal cannula or non-rebreather masks are inadequate for low-pressure atmospheres.

Ventilatory Support

Either an oxygen- or electrically powered portable ventilator must be available for intubated patients, regardless of their respiratory status. The ventilator must be adjustable to provide for both normal ventilation and hyperventilation. A capability to provide positive-end expiratory pressure (PEEP) would benefit many diseases. It is unlikely a ventilation device that is manually operated by an attending crewmember would be sustainable throughout the recovery process.

Aspirator (Suction Equipment)

A suction device with appropriate catheters for removing the fluids that could obstruct respiration should be available within the ACRV. In a winged ACRV, this equipment could be used at any point in flight. But, even in other ACRV configurations, suction following station separation but prior to atmospheric reentry or subsequent to splashdown could be lifesaving. Suction devices for a nasogastric tube and urinary catheter should be available to provide intermittent and continuous suction, as required.

Monitoring Equipment

In addition to interventions, continuous monitoring of patient status is critical. The following equipment is important to perform this function:

1. Electrocardiograph (ECG) Monitor/Defibrillator – Provides support, at a minimum, by a three-lead ECG monitor with a defibrillator and a synchronized cardioversion. Through-the-paddle monitoring may also be advantageous in rare circumstances. An adhesive pad defibrillation system could provide the capacity for remotely ordered defibrillation or cardioversion when ground medical personnel are aware of significant dysrhythmias transmitted by telemetry. It would also be useful to minimize electrical arcing in a potentially oxygen-rich environment. If the device has a transcutaneous (external) pacing capability, pacing could be achieved through adhesive pads. An auto-defibrillation capability option may also be useful.
2. Blood Pressure (BP) and Pulse Monitor – Provides continuous evaluation of BP and pulse rate for the severely or critically ill patient, either by an in-flight attendant or via telemetry with ground crews.
3. Pulse Oximetry – Continuously estimates oxygenation throughout recovery.
4. Urinary Catheter with Temperature Sensor – Indirectly monitors systemic perfusion by kidney function and core temperature.
5. Computer Integration/Database – Maintains or transmits data for real-time intervention and post-recovery review.

Cardiovascular Support

A portable cardiopulmonary bypass or ventricular assist device could maintain perfusion in flight.

Drug Infusion Devices

In addition to the standard IV catheters, tubing, and bags that will provide various solutions and drip rates, a flow pump is needed to maintain and regulate the infusion. Gravity flow is not feasible in orbit or during reentry, nor may it be possible after landing or prior to rescue owing to uncertainty as to crew orientation in a floating vehicle. IV tubing that will be used with an IV pump should not include the usual “drip chamber” since air might enter the tubing and cause liquid separation.

If the ACRV design selected is a low-gravity, winged vehicle, no additional infusion equipment should be required because in-flight administration by a medical attendant would be possible. In a high-gravity, ballistic-style or Apollo-derived vehicle, no care during reentry could be initiated by an attendant; even continuation of care generally would be impossible. Depending on space and weight limitations, it might be possible to design and incorporate equipment that would permit ground-controlled administration of medications and fluids through established IV lines.

Medications

The list of medications carried will be determined largely by vehicle selection. This, in turn, will influence space and weight limitations and the crew’s ability to administer drugs during flight and immediately post-flight.

IV fluids must be carried since they can be initiated preflight. Fluid selection can be limited to Dextrose 5% in water to maintain a medication line, and to a pH-balanced isotonic crystalloid solution for volume repletion. As the development of synthetic oxygen-carrying blood substitutes progresses, it might also be considered. All fluids must be carried in sufficient quantity to allow for significant loiter and recovery times.

If administration is possible, the following medications would be useful:

Epinephrine HCl, 1:1,000	Morphine Sulphate
Epinephrine HCl, 1:10,000	Furosemide
Aminophylline	Mannitol
Atropine Sulfate	Haloperidol
Lidocaine HCl	Dexamethasone

Bretylium
Dopamine HCl
Naloxone HCl
Meperidine HCl

Diazepam
Phenobarbital
Pancuronium
Sodium Succinylcholine

The dose, function, and complications of each medication would be available to the administering crewmember using a method similar to that employed on the space shuttle medical system.

Immobilization Equipment

Spinal and extremity immobilizers will be required equipment in the HMF and might also be housed on the ACRV. Wooden or fiberglass spine boards, long in use, will need to be padded carefully before a patient is subjected to high-gravity forces. A vacuum-splint-style spinal immobilization device, available in the pre-hospital-care market, may offer better protection than standard spine boards because the device's ability to mold to any configuration. Questions about the advantages of soft padding versus the risk of vertebral movement will have to be investigated regardless of the device selected. Similarly, vacuum splints may be preferred for extremities that do not require traction. Board or wire ladder splints and conforming splints such as the SAM splint are also versatile options. Traction splints must be chosen in view of space limitations in both the HMF and the ACRV. For this reason, the Sager traction splint has been found useful for helicopter aeromedical transport.

Pneumatic antishock garments (PASGs) should be available, although they most likely will be stored in the HMF rather than in the ACRV. A PASG, in addition to providing immobilization for fractures of the pelvis or lower extremities, may provide a hemostatic effect for intra-abdominal, retroperitoneal, or extremity bleeds. It also will temporarily elevate BPs in hypotensive patients. A ground-controlled pump to inflate the PASG during reentry would be useful. Vacuum splints and the PASG are potentially significant hazards because they rely on gas pressure to achieve their effect, and gas pressure is subject to considerable changes that depend on outside pressure. So, either a stable cabin pressure of 14.7 psi would need to be guaranteed or a device inflated with a substance less vulnerable to changes in outside pressure would be needed.

Miscellaneous Equipment

A Heimlich valve is carried to use with chest tubes. This valve is more practical for transporting patients with severe chest injuries than for trying to maintain a water seal.

Summary

Two equipment considerations are: (1) the type of equipment selected and (2) its configuration within both the HMF and the ACRV. The influence of equipment on ACRV payloads and on the ACRV's "flying" ability is also important. Included in these considerations is the need for a highly flexible and functional transport litter—a device that will be completely designed rather than modified from the relatively limited pre-hospital-care choices.

CONSIDERATION 7: Equipment for transporting a patient to the ACRV and securing the patient's position in the ACRV should be detailed, including demands on payload capability, ACRV maneuverability, and the position and role of other crewmembers.

Facts/Comments

While it is possible that no medical equipment will be needed for certain ACRV uses, in a medical transport module portable equipment may significantly impact the overall performance capability of the ACRV. A number of factors are important when selecting medical equipment.

Weight/Volume

The weight and placement of an ill/injured crewmember in a recovery system together with additional equipment may affect the maneuverability and operation of a spacecraft. The weight of all possible equipment and the maximum number of transport personnel may place an upper limit on certain payloads. The size and shape of equipment, how the equipment fits together, and equipment accessibility are also factors that might affect overall

performance. Optimally, commercial components may be rearranged into lightweight modules with several functions.

Seats/Restraints

Crew seat, restraint, and harness design should provide minimal risk of injury to healthy or uninjured crewmembers. Special equipment, such as a seat with litter capability and impact attenuation, is important to protect an injured crew. The ability to position the patient in positions other than and inclusive of the standard position for reentry is necessary. Optimal transport positions for different illnesses or injury may vary.

For example, if an Apollo-derived design is used for medical transport, the best location for an ill or injured crewmember would be in the middle of the bottom row of seats situated on a removable upper middle seat. The attendant would ride next to the patient with required therapeutic and monitoring equipment on the other seat. When necessary, other crewmembers could ride on the upper row. This would separate the other crewmembers from distractions related to the ill/injured crewmember. The ill/injured crewmember's seat should be separated from the other crew seats so that procedures could be performed without affecting the crew or the ACRV systems. Another possibility is designing two other seats, possibly on the bottom row, that will have basic immobilization capability. Each seat may be served by an individual set of equipment or from a central unit. This second option must be considered as a possibility should multiple crew injuries occur.

Transport Litter

When a crewmember is seriously ill or injured and the decision is made to transfer him/her from the HMF to the ACRV, a transport litter or patient restraint system is vital. To prevent inconvenience, discomfort, and possible injury caused by being transferred from one supporting structure to another, the transport litter should offer a minimal burden to the patient and transport personnel. It should be easily maneuverable between the space station airlocks and the entrance to the ACRV. The ACRV access door should accommodate the restraint system in a worst-case patient posture and orientation without significantly hindering patient loading or unloading. Rapid entry and egress must be possible in both microgravity and 1-G environments.

Ideally, the litter used in the HMF could be removed from a supporting structure and used for transport to, in, and from the ACRV. This litter should include a spinal immobilization device. Or, be a "patient pod" could be inserted and removed from the ACRV as a single structure. Also, to allow for rapid removal of a severely injured/ill patient from the confines of an ACRV vehicle, the patient pod could contain patient monitoring and care equipment that could be operated telemetrically. If flotation devices are incorporated in the pod, survivability would be enhanced—even in the event of ejection prior to ocean rescue by helicopter rescue forces.

Crew clothing will largely depend upon vehicle configuration and the selected environment. It is unlikely that a pressurized space suit would be appropriate for the patient.

Indications for Medical Transport

Indications for medical transport should be based on defined capabilities as well as on the HMF and crew, reentry forces involved with the ACRV, physiologic tolerance of these forces on individuals with different illnesses and injuries, and influence of time and treatment methods on specific diseases.

CONSIDERATION 8: The decision to transport ill/injured crewmembers includes the training of on-site personnel who are making the decisions, resuscitation capability of the HMF, deconditioned status of the patient, ACRV reentry profile, severity and natural course of the illness or injury, and availability of the shuttle. Only limited human experience with prolonged spaceflight can be used as a reference in this work.

Facts/Comments

The HMF is planned to care for Class I (mild) and Class II (moderate) illnesses, and to temporarily stabilize some class III (severe) illnesses prior to removal⁽¹⁾. It will have adequate diagnostic and therapeutic materials to diagnose and care for common injuries. Crewmembers will be removed from the HMF by ACRV or space shuttle.

The station should have a designated medical officer. Depending on the medical officer's level of training, he/she will have enough experience and training to diagnose and treat most illnesses and injuries and to know when HMF capabilities are exceeded or when a crewmember must be transported from the station. Inadequately qualified medical officers, by providing inadequate care, could allow Class I and II illnesses to progress to Class III status.

Prolonged microgravity exposure will profoundly affect the disease state acutely after injury or illness, during a return flight, and following exposure to Earth's environment. The impact of cardiac and musculoskeletal deconditioning together with neurovestibular changes will impact the patient's condition both en route and during recovery. This would limit the ability of an accompanying crewmember to function usefully. Several sources have documented how these conditions could cause the crew to experience orthostatic hypotension, an inability to move unassisted, and possibly disabling neurovestibular symptoms⁽²⁾.

The ACRV will have adequate space and facilities to provide patient care during and after reentry. The gravity profiles and recovery mode will play heavily in the decision to transport a patient. The ACRV's gravity profile must not prove detrimental to a patient's or rescuer's functioning. Vehicle recovery must be rapid (> 1 hour) and the vehicle must be able to maintain life support and power systems while waiting for recovery. The shuttle, which would be assumed to be readily available for use, could be reserved for patients who require transport in a sophisticated, relatively low-gravity vehicle.

Summary

Crewmember removal must be planned with the patient in a protected environment that will cause no further harm during removal. Although this situation is unlikely, the ACRV is best used in medical conditions that are minimally or not at all affected by this transport-and-recovery profile. The ACRV is also used when there is no time to wait for shuttle deployment and the patient can only survive if rapidly removed. If possible, the space shuttle is used when more equipment and more cautious transport is needed in a stable or a complex patient. This is because it affords a choice of landing areas and the possibility of other crew to help care for a patient, and its use does not require removing crewmembers other than the patient from the station.

CONSIDERATION 9: The value placed on a person's life or limb is emotional and complex. Before a patient is removed from the station, it is necessary to address the inherent risk and benefits to that patient, the crew, and the mission itself.

Facts/Comments

The cost of a space station runs into billions of dollars. But, the cost of a person's life has an incalculable as well as an emotional value. The cost of rescue by the space shuttle is estimated at \$200M (in 1989 dollars). The cost of ACRV deployment has yet to be determined, but it will not be inexpensive.

The government and the public value safety and the availability of medical care. To them, a crewmember's life is not expendable. However, in terms of the mission, a crewmember's life may not equal the risk of jeopardizing the crew's and station's viability by attempting a rescue. Or, simply put, the results may not be worth the risk.

Loss of an injured or ill crewmember will lessen effectiveness. The impact of illness or on-orbit death will affect the crew psychologically. Crewmembers are at risk during return and may be lost if recovery is prolonged or the vehicle cannot be located. Some transports may be so precipitous it will be difficult to assess benefits until long after the event. Many situations cannot be planned for, and the benefit of transport must be weighed at that time.

Summary

The space station must have a viable plan for patient evacuation—a plan that limits the loss of crew effectiveness and minimizes danger to patient and crew. All alternatives should be explored before a crewmember is allowed to die in flight. Simple or easily manageable illnesses should not be transported if supportive care can be safely provided on board the station without disrupting the mission or the crew's psychological fitness. Each case will need to be studied to the extent allowed by time and personnel.

CONSIDERATION 10: A number of disease possibilities and their evolution in a space station setting require discussion. The major potential disease categories are listed.

Facts/Comments

The spectrum of potential neurologic problems includes cerebrovascular accident (CVA), head injury, and spinal trauma (neck injury). These conditions require thorough diagnosis and meticulous care.

Subarachnoid hemorrhage comprises 8% of CVAs. Its peak incidence occurs between 35 and 65 years—the age range of most station crewmembers. Subarachnoid hemorrhage is anticipated to be the most common cause of CVA on the space station. Its presence is hard to detect on routine medical examination, and the HMF capability does not add to the diagnosis. It is likely that, depending on the medical officer's skills, lumbar puncture will be part of the diagnostic testing. If the patient survives initial bleeding, treatment involves supportive care and elective surgery. A subarachnoid hemorrhage is at risk for rebleeding after 1 to 6 weeks.

Head injuries are common. A head injury occurs worldwide every 15 seconds, with one death occurring every 12 minutes. Indeed, head injury comprises 25% of all deaths due to trauma³¹. Evaluation of head trauma is specific and repeated at regular intervals. The HMF will not allow for CT scanning capability. The availability of plain radiographs and other simple diagnostic techniques within the HMF is of limited usefulness.

Spinal trauma with cord injury occurs commonly, both alone and associated with other injuries. The rate of spinal cord injury in the United States is 50 in 1,000,000, and the diagnosis often can be made on examination. Most unstable spine injuries, with or without cord injury, may be diagnosed by plain radiography.

Rapid, definitive care in any of these traumas is the only way to save a crewmember's life. The decision to transport will have to be made rapidly and accurately; for this, the ACRV is likely to be used. During transport, restraint and immobilization systems will have an important role to play. The capability for prolonged respiratory paralysis and barbiturate coma, along with other advanced medical therapies, may be necessary.

A severe head injury or spontaneous cerebral hemorrhage may progress rapidly to the point that care on the station may not be feasible and a return to Earth may be the only chance to save a crewmember's life. However, return to a 1-G environment and the accompanying transient increase in gravity can deleteriously affect a patient's cerebral tissue through fluid shifts and hypotension. Unstable spinal column injuries may impinge on the cord if immobilization does not overcome gravity forces. There is also a loss of tone in the muscles of the spine that on Earth help to splint these injuries by protective spasm.

Care on board the space station may not only be adequate in subacute situations but may actually be beneficial. The microgravity environment may allow temporary support for patients because of the ease of transfer and immobilization. Long-term care may be undertaken if the patient has sustained a head injury without focality. Though the evolution of cerebral edema in the microgravity environment is unknown, emergent transport is unlikely to make a difference in this case. The timing of intervention in subarachnoid hemorrhage may allow for less urgent transport after the initial event. And, although microgravity may slow healing of bony spine injuries, its effects on the edema of the spinal cord are unknown. Clearly, research in some of these areas is necessary to make educated decisions about the care of these injuries.

The type of neurologic problem and the rapidity of evolution and severity of signs and symptoms will dictate transport. Some conditions will be fatal within a short time. The patient with a probable intracranial injury or hemorrhage with rapidly evolving signs is a candidate for transport via ACRV. Spinal injuries and those intracranial processes that are stable after acute insult should be supported and transported via shuttle. A smooth transition to the most complete care will reduce the risk of additional injury in a possibly salvageable patient.

Head, Eyes, Ears, Nose, and Throat (HEENT)

The spectrum of illnesses and injury to a crewmember's HEENT is large. Some illnesses and injuries will require expert care to save a vital sensory function.

Facts/Comments

Most eye injuries are minor and can be treated with simple procedures and medications. However, this does not include penetrating injuries, lens injuries, or acute retinal detachments. Ear injuries can be treated conservatively and rarely require immediate care. Nose and mouth injuries can profusely hemorrhage, although it is hoped that most of these could be managed with local pressure and the equipment provided. Nevertheless, the station should have a complete diagnostic and therapeutic complement of instruments and medications to deal with most HEENT conditions.

The treatment of ophthalmologic and otologic conditions should not change in microgravity. An exception to this is that conditions presenting neurovestibular symptoms may worsen in microgravity. The rate of aqueous/vitreous fluid loss may increase as a result of decreased or increased gravity forces and decreased cabin atmospheric pressures.

Summary

Rapid deployment of the ACRV will probably not occur for any HEENT injury or illness that does not endanger eyesight or hearing. By contrast, with an illness or injury for which there is only temporizing treatment—e.g., intraocular hemorrhage—rapid transport by ACRV may be indicated.

Chest

Chest traumas account for 25% of all trauma injuries in the United States. A chest injury is a likely contingency for the crew of the space station.

Facts/Comments

Roughly 85% of chest injuries can be handled nonsurgically. Definitive care usually consists of tube thoracostomy and drainage of air or fluid. The remainder of chest injuries may entail surgery that may or may not be within the scope of the HMF. Respiratory support can be provided along with other procedures.

The HMF should be able to supply chest radiographs, oxygen, a ventilator, and the surgical capability to handle the majority of chest injuries. Some disorders that are sensitive to atmospheric pressure changes—e.g., pneumothorax—would be treated prior to transport. Other cases that could not be treated in the HMF would be rapidly reviewed for the best course of action. If the patient can be stabilized, most cases requiring surgical support may be transported to Earth by ACRV or shuttle.

Summary

The HMF and the medical officer should be able to provide all lifesaving techniques in chest trauma including thoracotomy. The latter is necessary in pericardial tamponade following a penetrating injury to the chest. In an emergency, timely cardiac or respiratory repair—including selective aortic cross clamping—may be lifesaving. Definitive care will require rapid transport.

Abdominal Trauma

Penetrating or blunt abdominal injury is common in trauma. Rapid diagnosis and treatment are paramount in patients suffering from abdominal trauma.

Facts/Comments

A traumatic abdominal injury can involve many organs—hollow, solid, and vascular—as well as the bony pelvis. The injury itself may be self-limiting, involving only hemorrhage in a closed space; e.g., splenic hematoma. But, the patient can bleed into the peritoneal cavity and rapidly exsanguinate. The rupture of a hollow viscous is a significant problem that requires early definitive care. While deciding on the need for surgical intervention is key to successfully evaluating abdominal trauma, this is a difficult decision to make even in a I-G environment. Beyond physical findings, peritoneal lavage is probably the main diagnostic procedure that would be performed in the HMF to diagnose abdominal injury; its modality is about 92% sensitive. Lavage can be supported by simple laboratory tests and observations. Patient care would be predicated on the need for rapid surgery. Many of these cases are obvious because of associated symptoms or the hypotension or decompensation of a previously stable patient. Transport by ACRV depends on the additional constraints of access to definitive care after recovery.

The HMF should be able to support the early treatment and diagnosis of abdominal trauma—excluding CT scanning—and volume repletion with crystalloid and available blood products. Nasogastric and bladder drainage will also be available. PASG's will be available for circulatory support and splinting. Although the HMF will not support laparotomy, this procedure may be available in extreme circumstances. The ACRV should be capable of providing continuing care and life support systems. Surgical care is assumed to be available within 2 to 4 hours after leaving the space station via an ACRV. Care of a patient who is rapidly exsanguinating may be impossible in the HMF, although the use of surgical facilities in the HMF may be the only alternative to saving the patient's life. The subacute abdomen remains a problem that may be either handled on the station or through being transported to Earth in a timely and controlled manner via an ACRV or a shuttle. The question of transport will be determined following the crew medical officer's assessment of patient condition and prognosis. Consultation should also be available from ground-based resources. Diagnosing a need for surgical exploration in abdominal trauma is a difficult process. Errors in timing and judgment will occur. The availability of surgical suites and extensive medical resources has contributed greatly to the care of a patient with abdominal trauma. Care of these injuries in space and timing safe transport back to Earth will be some of the more difficult situations for the crew medical officer.

Genitourinary (GU) Trauma

An injury to the GU system is usually not immediately life threatening, but it may impair immediate and future urinary and sexual function. Therefore, a GU injury best lends itself to timely transport for definitive care.

Facts/Comments

Most injuries to the GU system either obstruct urine flow or disrupt urogenital tissue. External injuries can be repaired, with function restored or stabilized, and bladder drainage can be obtained. More significant internal injuries can be life-threatening either from retroperitoneal hemorrhage or infection.

The HMF should have the equipment needed to allow repair of simple external injuries. It should also have the means to stent the urethra and to provide suprapubic bladder drainage. The crew medical officer should be qualified in diagnosing and providing primary treatment of GU injuries. The station facility should be equipped with catheters, etc., of appropriate sizes and types. Since microgravity may cause an inability to drain a patient's bladder, there may be a need for a negative pressure device to provide drainage. Most GU system injuries—unless associated with rapid exsanguination from direct, blunt, or penetrating trauma to the kidney itself—can be transported under more controlled conditions that will require little in-flight support and will permit loiter for some time before definitive care is administered. The ACRV would be ideal for these situations.

Musculoskeletal Trauma

An injury to any element of the musculoskeletal system can be, at worst, a limb- or life-threatening event. Healing patterns are well known in the I-G environment. Repair of musculoskeletal injuries in a microgravity environment, by contrast, are not at all well understood and may not be trivial, even in the simplest injury.

Facts/Comments

The return of function to a fractured bone relies on the orderly deposition of bone and remodeling of that bone⁽²⁾. Long-term exposure to reduced gravitational forces causes loss of bone density due to reabsorption and calcium excretion. These two processes may directly conflict with one another and may not allow normal bone

healing. Loss of muscle mass in the microgravity environment may affect the repair and recovery of function in musculoskeletal injuries of the patient's extremities, spine, and pelvis⁽²⁾.

The effect of microgravity on fracture healing is unknown. A fracture in microgravity that would be inconsequential on Earth may result in a significant nonunion if the patient is allowed to stay in microgravity.

Injuries to tendons, vascular elements, nerves, open fractures, and intra-articular lacerations require prompt surgical treatment. While the HMF may offer basic surgical support, microsurgery and rehabilitation of injuries along with complex orthopedic procedures are unlikely to be available. The problem with open fractures occurring in microgravity is that the patient may experience an altered immunologic response with loss of T-cell function. This may potentially adversely affect the immunologic system and its ability to prevent tissue and bone infection both in flight and post ACRV/shuttle recovery.

The HMF will have facilities that permit the initial stabilization and treatment of orthopedic and other musculoskeletal injuries. Use of the ACRV or shuttle should allow traction and stabilization to be maintained during transport.

In most instances, complex musculoskeletal injuries should be transported to Earth in a timely manner. Amputations or major vascular injuries may be the only indication for emergency transport. The ACRV may serve well in either scenario. Open fractures and more complex injuries should first be stabilized and initially cared for in the HMF. The facility should be able to provide adequate surgical and orthopedic support. The crew medical officer should be trained in such care and should have adequate access to expert consultation on the ground. Research into bone repairs in the microgravity environment is necessary.

Infectious Disease

The space station will not be a sterile environment. It will be colonized with microbial life that will, in certain cases, have pathogenic capabilities. Rotating crewmembers may spread infections to other crewmembers. Epidemics may occur within the station itself. The possibility of secondary infection in response to an initially trivial injury is also a concern. Food poisoning might occur. These problems may or may not require transport, but they would definitely affect crew efficiency.

Facts/Comments

The scope of infectious disease and its complications and sequelae are tremendous. Little data exists on the presentations and treatments of infectious diseases in microgravity. Generally, since crews on long-term missions are quarantined to prevent community-acquired infections, there have been few incidents of serious infectious disease. Skylab research shows there is some alteration of white blood cell function that primarily affects T-cell function⁽²⁾. This decrease in T-cell responsiveness has also been shown to persist for a varying time on return to Earth. The implications are not yet completely, but clearly microgravity alters the human immune system. Methods of treating infectious disease on the station should be a minor problem, but the spectra of serious life-threatening or contagious, disabling disease could have devastating effects. It may be impossible to care for rapidly spreading diseases such as severe gastrointestinal symptoms and still adequately maintain the station. Large numbers of patients or recurrent cases may overwhelm HMF supplies. The possibility of a new or an altered microorganism, which may pose a threat to the general population on Earth, is another consideration in returning a crewmember to Earth.

The HMF should be supplied with a wide array of antibiotics as well as with the means to culture and identify organisms. There should be a way to isolate contagious crewmembers and to provide adequate supportive care. The HMF should therefore be supplied to care for a full complement of crewmembers, any or all of whom may be infected. Protocols should be established to prepare for wide disease spread and its possible effect on the integrity and mission of the station. At the earliest sign of spreading infection, infected crewmembers should be returned to Earth, decontamination should be instituted, and, possibly, the station should be re-crewed to save the mission. Transport of a septic or seriously locally infected patient should be expedited. The use of the ACRV should be predicated on patient stability.

Cardiopulmonary Conditions

The danger of cardiovascular and respiratory illness or injury is real. The possibility of hypoxia, toxic inhalation, decompression sickness (DCS), and even cardiac arrest also exists. There are standard approaches that can be used to treat these injuries. Their eventual course and subsequent care should be anticipated.

Facts/Comments

The space station can be equipped to provide advanced cardiac life support and prolonged ventilatory care. A stabilized patient could be maintained on board until orderly transport is arranged.

DCS, known to occur after extravehicular activities (EVAs)⁽²⁾, can be effectively treated with hyperbaric oxygen therapy. Since EVAs are anticipated to be commonly performed from the space station, DCS will be a risk, but DCS rarely advances to a life-threatening entity.

The potential for exposure to toxic fluids and gases is significant. The shuttle has been exposed to at least 10 such substances, and it is unlikely that the station will experience fewer. Some of these substances are ammonia, freon, hydrazine, nitrogen, hydrogen, and nitrogen tetroxide. Most inhalation injuries will require supplemental oxygen and supportive care. More severe inhalation injuries will require ventilatory and cardiovascular support.

HMF facilities could handle an uncomplicated myocardial infarction. The need for and use of thrombolytic therapy in this setting must be considered.

The HMF should also be able to provide prolonged ventilatory and circulatory support along with monitoring capability for patients, and the crew medical officer should be sufficiently skilled to care for them. The space station should have a two-place recompression chamber to enable DCS to be rapidly and correctly treated.

Summary

Microgravity may adversely affect the cardiovascular system and further complicate cardiorespiratory disease⁽²⁾. The effect of gravity on reentry may adversely affect outcome as well. The care of patients suffering from problems with the cardiovascular system should center on stabilization and timely transport. The transport should be timed maximally to help the patient, and to maintain crew and mission integrity. Research is needed into the response of compromised cardiovascular and pulmonary function when exposed to high-gravity reentry profiles.

Physiological Readaptation to 1-G

The human body, after its return from microgravity, must readapt to Earth gravity. This process occurs in every person to some extent, even after only a few days in space. There are three basic physiological considerations: (1) orthostatic intolerance due to cardiovascular and fluid/electrolyte changes, (2) neurovestibular changes, and (3) musculoskeletal changes. Each has been documented in returning crewmembers. Any one or all three could severely limit performance after reentry. Many crewmembers are sufficiently readapted to be able to walk satisfactorily after 10 to 20 minutes. Others have great difficulty even after 10 to 20 minutes and will require several hours to get back their "Earth legs". Several shuttle crewmembers have experienced serious neurovestibular symptoms that have totally incapacitated them for up to 1 hour or more post landing. There is also evidence that decrements in mass perception and discrimination may occur immediately post landing. The U.S. space program has had limited experience with long-term missions; but, after Skylab (the longest flight of which lasted 84 days), crewmembers were relatively incapacitated for as many as a few days after landing.

Readaptation is a great concern for an ACRV scenario. Even in the best of situations, where the entire crew is deemed "healthy," there is considerable evidence that suggests the readaptational process will severely limit a crewmember's ability to perform the complicated physical actions that might be necessary to effect a rescue. An ill or injured crewmember might not be able to make physical efforts on his/her own behalf, and the physiologic responses may not be the same.

It is important to consider the Russian experience. After a record-setting 237 days in orbit, the Salyut crew was unable to lift their arms to unbuckle their lap belts and had to be physically carried from their spacecraft. Significantly more research is needed into the physiologic response of the deconditioned individual to pathologic processes. As an example of the limited database for this information, the most recent available paper on deconditioned tolerance to Gx acceleration was written in 1965⁽⁴⁾.

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Transport Protocols

Should a medical emergency occur that is severe enough that the HMF cannot provide adequate care to an ill/injured crewmember, a decision must be made on the feasibility and advisability of returning that crewmember to Earth. Physical examination results, pertinent laboratory and radiological findings, and related information would be transmitted to JSC; and the transport/no-transport decision would be made after consulting with the crew, the flight medical officer, other Medical Operations personnel, and, possibly, outside consulting teams. This group will also need to coordinate with space operations and rescue team efforts, and to assess risks associated with various loiter times, splashdown or landing sites, and other flight-associated hazards versus the time required to obtain definitive care for a patient.

CONSIDERATION 11: Coordination with station and ground rescue forces is needed to seek the optimal window of opportunity for reentry. This must take into account the availability of rescue forces with respect to the station's position. (See Search and Rescue.)

Facts/Comments

The time-axis is influenced by many factors, including patient condition, potential for intervention in the HMF, weather at recovery sites, loiter time, potential station movement, positioning of selected recovery forces, and medical capabilities of recovery forces.

CONSIDERATION 12: Preflight patient care protocols need to be developed, including general systems checks and items for specific disease entities.

Facts/Comments

Some injuries are non-survivable regardless of where they occur, and other injuries will not tolerate the stresses of reentry from Earth orbit. Preflight patient care delivered in the HMF will significantly enhance survivability during reentry and recovery. The general areas, for which function checklists need to be developed, include:

1. ACRV Systems – Environmental
 - Temperature, pressure, oxygen
 - Power
 - Communications
2. Medical Life Support Equipment
 - Airway and respiratory support
 - Fluid-replacement delivery system
 - Monitoring
 - Medications
 - Splinting, immobilization, and patient restraint

Patients must be appropriately restrained to prevent them from sustaining further injury from their own movements within a seat or stretcher and against the forces involved with reentry, landing, and recovery.

A patient with an altered level of consciousness or an underlying disease process that could adversely affect consciousness, airway patency, or respiratory capacity should have a protective airway inserted prior to placement in the ACRV. Optimally, an ETT should be used and a nasogastric tube should be placed afterward. Both tubes need to be secured to prevent movement. If ETT placement is not feasible, a surgical cricothyrotomy or a tracheal lumen airway is also an option. An IV line (peripheral or central) is placed to provide access for medication delivery or volume resuscitation.

Sedation must be considered not only to manage pain but to prevent patient movement that could dislodge airway or splinting devices, or aggravate patient injury. Sedation may necessitate intubating a patient who would not otherwise require it so that he/she can be placed on a ventilator to guard against the onset of respiratory depression in flight. Circumstances must be considered and detailed that would warrant administering a paralyzing neuromuscular blocking agent such as pancuronium or succinylcholine.

Specific physiologic parameters to be met before transport should also be considered. Specific focus should be placed on protocols by disease category, including those discussed below.

Head and Neck Injury

Intubation and hyperventilation must be initiated rapidly in case of significant head injury. When an expanding intracranial lesion or other indication for rapid neurosurgery beyond the capacity of the HMF occurs, treatment is urgent. This situation may justify risks that would not otherwise be considered involving ACRV transport. Prior to transport, IV access is established and fluid is infused at the slowest possible rate unless hypotension or hypovolemia is also present. Diuretics, corticosteroids, barbiturate coma, and anticonvulsants should be considered.

Unstable spinal injury—with or without neurologic deficit—requires preflight immobilization that, if possible, should be applied at the scene of occurrence. Microgravity conditions may ease application of spinal immobilization devices, but reentry from orbit and splashdown with its potentially high gravity loadings, particularly in a wingless ACRV, will require extensive protection against vertebrae movement. A vacuum-splint-style spinal immobilization device may offer better protection than standard spine boards will. A major challenge is developing techniques and devices, which provide on-site immobilization without risking cord disruption, and adequate impact attenuation while restricting spinal motion under high- and microgravity conditions.

Head, Eyes, Ears, Nose, and Throat

Assuming that impending loss of vision is the most likely reason for returning to Earth, little specific preflight or in-flight care is needed. Supine positioning is generally recommended for transporting these patients, but there is no information concerning the potential effects of high- or microgravity conditions on ocular injuries. Low atmospheric cabin pressures may also increase the risk of ocular fluid loss. Preflight therapy aimed at reducing intraocular pressures may prove beneficial in some cases.

Chest Trauma

The patient should have IV access with an appropriate resuscitation fluid started, and, in most cases, a chest tube with a Heimlich valve placed. If the airway is at risk or if the airway may lose its protection or patency, an ETT is placed as part of the preflight protocol. Pericardiocentesis by catheter or window techniques, or thoracotomy with or without aortic cross-clamping may be performed in the HMF. If performed, the patient will require appropriate support during ACRV transport. Sedation or analgesia/anesthesia will typically be required.

Abdominal Trauma

In addition to IV placement, sedation, and possible intubation, a PASG should be placed on the patient. Preflight inflation of the PASG will depend on the patient's condition and whether the garment can be inflated during flight. The likelihood of spinal cord and renal infarction before rescue will most likely obviate the use of aortic cross-clamping.

Genitourinary Trauma

Analgesia will be needed prior to transport. If possible, urine should be adequately drained. If the bladder must be continuously emptied, a suction pump should be used.

Musculoskeletal Trauma

Depending on the nature of the injury, transport may have a high or low degree of urgency. Optimal timing will need to be discussed with medical personnel on Earth. Affected limbs must be adequately splinted prior to placing a patient in the ACRV. IV analgesia will be essential as high gravity conditions with a fracture are likely to cause severe pain. PASGs or air splints may be used for hemostasis and splinting, even in extremity amputations,

and are less likely to cause significant tissue damage than narrow tourniquets. This depends on the pounds per square inch (psi) of surrounding atmosphere, or the ability to maintain constant pressure within the splint or PASG. Traction will be needed for some injuries. Amputated parts will need to be packaged to keep them dry and chilled, without freezing.

Burns

Many burns will be cared for in the HMF without necessitating an early return to Earth. Burn patients who need to be evacuated from the station will require initiation of analgesia and IVs for fluid replacement preflight.

Cardiovascular/Respiratory Emergencies

Any patient returned to Earth as a result of a cardiovascular/respiratory emergency will require an IV infusion and, probably, analgesia. Intubation and ventilation may be required in cases of heart failure, shock, and severe DCS. Monitoring apparatus must be applied prior to flight. A 12-lead diagnostic ECG should be performed in the HMF, and any thrombolytic therapy being considered should probably be completed before departure. Post-thrombolytic exsanguination due to high-gravity reentry injury may be a risk. The risk of anticoagulation will also need to be considered.

In cases of DCS and air embolism, repressurization should be initiated immediately on the station. Oxygen therapy should also be initiated, and the usual IVs, monitors, and analgesia should be instituted before placing the patient in the ACRV. A similar sequence is necessary for toxic inhalations.

Psychiatric Emergencies

In a psychiatric emergency, physical or pharmacological restraints should be applied, as required, to prevent any possibility of the patient interfering with controls on board the ACRV.

CONSIDERATION 13: In-flight patient care protocols are necessary. If possible, most resuscitation and stabilization will be performed in the HMF as a preflight protocol.

Facts/Comments

General Support Measures

Airway and ventilation must be maintained at all times if a patient is to survive. An onboard or a portable ventilator will likely be used, regardless of the vehicle. Suction may be important to preserve the patient's airway, but the use of suction in flight is probably not feasible in a ballistic or an Apollo-derived ACRV.

An IV infusion should be maintained throughout flight. A pumping administration device is needed to control fluid flow rates, maintain flow during varying gravity conditions, and prevent air entry into the tubing that could result in liquid separation and air embolism. A quantity of fluid adequate for flight duration, including loiter and recovery times, must be available to the patient before departing the station.

Installing a device that can instill a variety of selected drugs and fluids into the IV line would permit the flight medical officer in the ACRV to administer emergency medications during reentry and post-splashdown in vehicles with gravity characteristics that preclude active medical attention and intervention by crewmembers. The same device could be used in cases of abnormal orientation after splashdown, or when recovery is prolonged but other crewmembers are too weak or unable to deliver patient care.

Specific Problems

1. **Head and Neck Injury** – Any significantly head-injured patient must be hyperventilated during flight. Infusions of diuretics and/or corticosteroids can be continued. Anticonvulsants may also be needed. If a telemetrically operated drug selection device is unavailable and flight conditions prevent crew intervention, prophylactic anticonvulsant therapy should be strongly considered. If possible, the patient's head should be positioned above the cardiac level. The vacuum-splint style spinal immobilization device (currently available in the pre-hospital-care market) may offer better protection than standard spine boards.
2. **Chest Trauma** – In flight, the medical attendant or a physician on Earth should be prepared to adjust IV flow rates as necessary to manage hypotension. The patient most likely will be intubated and on a ventilator.

Although the possibility of a patient developing tension pneumothorax exists even after a chest tube has been placed, it is a rare event. In any case, needle thoracocentesis in flight will be impossible unless a winged ACRV or the shuttle is used for transport.

3. Abdominal Trauma – The capacity to adjust IV flow to maintain blood pressure should be available. Ideally, either a crew attendant or a ground-based medical officer should be able to inflate the PASG if the patient's condition dictates its use.
4. Musculoskeletal Trauma – Replenishment of IV analgesia may be required, depending on loiter time.
5. Burns – Fluid replacement and analgesia must be maintained during flight.
6. Cardiovascular/Respiratory Emergencies
 - Continuous ECG monitoring is essential. If possible, the capacity to provide defibrillation, synchronized cardioversion, or transcutaneous pacing through adhesive pads during flight would significantly enhance patient safety.
 - Although thrombolysis following infarction will most likely be completed prior to departure, it may be necessary to continue therapy to prevent reocclusion, and preparations should be made to deal with reperfusion dysrhythmias.
 - The effect of anticoagulation and its risks during transport and recovery must also be considered. In the event of cardiogenic shock, a portable cardiopulmonary bypass or a left ventricular assist device might preserve myocardial and cerebral perfusion during transport.
 - The station would be used to provide therapy for cases of DCS or air embolism. Whether this capability would be feasible or necessary in the ACRV needs to be discussed. Providing continuous therapy while en route to Earth may be impossible or impractical.
7. Infectious Diseases – Continuing antibiotic therapy and hydration should present no difficulty during flight. Optimally, the crew or ground-based medical officer should be prepared to administer epinephrine in the event of an anaphylactic reaction.

CONSIDERATION 14: Loading/unloading protocols need to be developed.

Facts/Comments

Ideally, any device hooked to the patient by wire or tubing will be permanently mounted to the litter or patient pod to reduce the chances for entanglement while moving the patient into or out of the ACRV.

IV patency and ETT position should be reassessed each time the patient is moved into or out of the ACRV. Adequate personnel should be available to assist with patient unloading, which can probably best be achieved after bringing the ACRV aboard ship rather than attempting it in the water. Standard quarantine will be adequate in most circumstances but may require modification if an unidentified infectious disease led to the need for transport.

Summary

Pre-flight and in-flight protocols will establish the parameters to monitor in a variety of potentially transportable disorders. Although pre-flight work will produce the majority of stabilization, in-flight interventions will maintain the patient's condition and allow landing and recovery in the best possible condition.

Transport Complications

CONSIDERATION 15: Crew-related complications during transport must be anticipated.

Once it has been determined that a medical transport from the station will take place, crewmembers must be prepared for in-flight transport emergencies. These emergencies present danger to the ill/injured crewmember and to anyone else on board the space station. These emergencies can be unexpected and can occur relatively sudden. By considering the various types of emergencies preflight, the onset of emergency becomes less unexpected and there is a contingency plan in place to handle the problem. Consideration of contingencies can indicate what equipment may be needed and what direct behavior and actions might prevent the contingencies from occurring. Transport complications considered are those related to the injured/ill crewmember and to the vehicle^(1,2).

Facts/Comments

Crewmember Transport Complications

Possible transport complications include hypoxia and gas expansion in flight. Additional attention must be given to the deterioration of the patient, the risk of further injury, and, ultimately, death.

The atmosphere selected for an ACRV must offer a compromise between the engineering and medical physiological needs of crewmembers. Decreased cabin pressure will necessitate supplementary oxygen to prevent hypoxia and may exacerbate pressure-responsive disorders (e.g., pneumothorax) and interventions (e.g., PASG). When preparing to transport a patient in the ACRV and if a lower-pressurized cabin is used, it is important to determine the patient's altitude equivalent with respect to oxygen status. A fully pressurized spacecraft could eliminate many of the physiologic effects of altitude secondary to hypoxia and would contribute to crew comfort.

The physiologic effects of decreased atmospheric pressure can also contribute to the gas expansion that can affect the closed and semi-closed cavities of the body, as well as gases within medical equipment. Preventing this effect is another advantage of a 14.7-psi environment.

Preventing deterioration of a crewmember's condition will depend on adequate preflight assessment and ongoing observation during flight. Medication and equipment can be chosen that might be needed should deterioration occur. Some major emergencies to be considered are hemorrhage, sudden cardiac dysfunction, and pneumothorax and pulmonary embolus. Patient history and other information gathered during preflight evaluation should indicate whether any danger of these conditions exists. Attention should be paid to avoiding prolonged pressure in the legs and venous stasis during long SAR attempts.

Although the patient may sustain additional injuries from acceleration, rotational, and impact forces, these forces should not cause injury if sensible precautions are taken. The security of the patient restraint at its attachment to the cabin floor and the method by which a crewmember is secured to the restraint are obvious parts to be considered. Danger is also likely to come from flying objects in the cabin, a result of insecure attachments of things such as fire extinguishers and IV fluid bottles. A repeated inspection of the cabin for loose and potentially detachable items is recommended.

CONSIDERATION 16: The possibility of ACRV-related transport complications must be considered.

Facts/Comments

Transport complications related to the ACRV include vibration and noise, fire, fumes, and depressurization.

Vibration sources include rocket engines and air turbulence. Most of these would be transmitted directly to the body of the ACRV and its contents. Properly designed crew seats and restraints should dampen some of the vibrations. And, although vibrations as such are not usually harmful to a patient or an attending flight crewmember, they can interfere with performing certain procedures. They can also add artifacts to monitoring equipment. Some vibrations can cause sufficient stress to hinder performance.

For the most part, noise sources are the same as vibration sources. The noise associated with vibration frequencies above 10 Hz is detrimental to crewmember care because of the physiological effects of those vibrations. Noise is also a stress-producing factor that can lead to decreased human performance and more rapid fatigue. It can interrupt communications not only within the cabin but in air-to-ground or air-to-air transmissions. Communications can be less accurate or misinterpreted. The interior of the ACRV cabin should be constructed with lining materials

that absorb some of the external noise and dampen the internal noise level. The shape of the cabin is important since any flat areas are likely to resonate with some frequencies of noise and act as a sounding board.

Although fire is unlikely to break out during reentry or landing, precautions should be taken as though it will. All crewmembers should consider evacuating the spacecraft to a safe distance as soon as practical since fire is always accompanied by fumes and can quickly increase the toxicity within the confines of a cabin. Supplementary oxygen sources—preferably a well-fitting mask on hood—should always be available for use. Proper knowledge and use of fire extinguishers is essential.

Sudden cabin decompression is one of the more serious emergencies that could occur during transport. The physiologic effects on the crew of this will depend on the rapidity of decompression, a relationship determined by the volume of the cabin to the size of the cabin defect. Supplemental oxygen should be available for use immediately to prevent DCS and hypoxia. After decompression, the ill/injured crewmember will need to be assessed for vacuum effects in body cavities and for cardiovascular and respiratory stability.

The degree of danger after landing is related to the landing area, the structural design of the spacecraft, and the skill of the crewmembers who are initiating proper egress procedures. Actions within the cabin must follow all security arrangements for normal and emergency egress procedures. The crew should be trained in how to rapidly locate and open emergency exits. All preparations for a rapid exit should be made before the incident, including knowledge on how best to quickly release an injured crewmember from his/her securing devices. The proper use of emergency flotation devices should be considered if the landing takes place on water.

Summary

Once the decision is made to activate the ACRV for transport, a considerable amount of coordination is necessary to ensure a smooth transfer at each step. Each step of this transfer may meet complications that could prevent successful recovery. Contingency plans at each phase of the transport will need to be developed to meet the unexpected. Planning, training, and simulating emergencies can promote an attitude that can lessen the consequences of most of these emergencies.

References

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Search and Rescue

SAR is a complex system of operations that requires coordinated activity among multiple disciplines to render aid in a safe and timely manner to persons in distress. The essential components of SAR include organization, equipment, trained personnel, communications, and emergency care. Since the network of SAR systems will be used only in the event of an emergency, it must be able to become operational in a short time. Although the timely arrival of SAR forces increases the survivability of victims, a limit may exist beyond which the use of SAR resources cannot be justified. For example, prolonged SAR operations are unwarranted when the probability of finding survivors has been exhausted.

Should the space station need to be evacuated, the shuttle may be used—depending on its availability and the urgency of the need to evacuate. If either the shuttle or a winged/maneuverable ACRV is used, a predetermined landing site can be chosen. In this scenario, SAR is a contingency plan that operates only if the intended rescue vehicle fails. If the ACRV is a ballistic or an Apollo-derived vehicle design, the landing site cannot be precisely determined and a recovery zone must be designated. In that case, SAR becomes an integral component of space station evacuation. The more flexible the SAR system is and the more completely its variables are considered, the greater the chance for a successful recovery.

CONSIDERATION 17: The time-axis intervention relationship of transport and recovery must be anticipated.

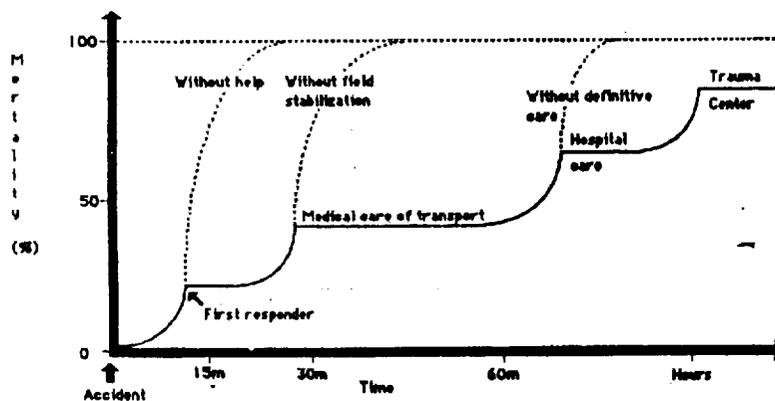
Facts/Comments

Several aspects of time must be considered when evacuating the space station. These include, but are not limited to, recovery time on Earth, elapsed time since the injury or discovery of a critical illness, and the amount of time required to recover space station personnel.

To optimize the amount of daylight available to SAR forces, dawn is the ideal recovery time. This would be vital whether SAR is a contingency plan, as in the case when a shuttle or a highly maneuverable ACRV is used, but especially so when SAR is an integral component of the recovery, as in an Apollo- or a ballistic-type ACRV. The decision to land at dawn should be made after considering how urgently the station must be evacuated, the ability to loiter in space—either in the station or on board the ACRV—the urgency of need for medical attention, and weather conditions at the proposed landing site.

When a crewmember is disabled, time is a critical factor in delivering definitive medical care. There has been extensive research on the effect of time to medical care for the victim of major trauma. If care is not initiated within the first “golden hour” after trauma is sustained, the mortality rate increases dramatically.

Figure 1



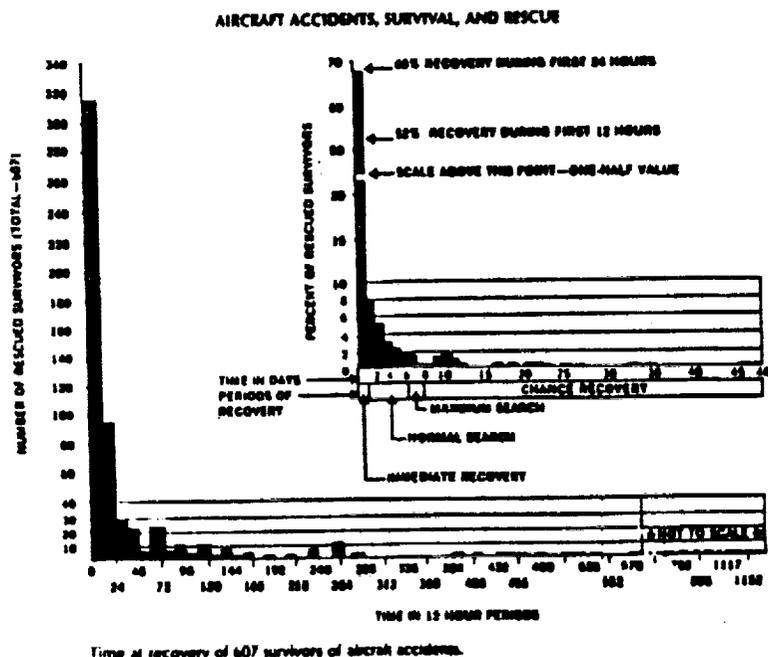
Mortality of trauma against time with resuscitation and definitive care. (Boyd, 1980).

Should a crewmember suffer a deteriorating illness, the effect of time to definitive medical care is less well-defined. Moreover, the deleterious effects of microgravity will complicate his/her condition further. In either a traumatic or medical emergency, the urgency for transport to an Earth-based medical facility would depend on the capability of station personnel to stabilize the disabled crewmember at the HMF prior to space station departure.

If the shuttle is used to evacuate a disabled crewmember, more extensive medical care can be rendered en route to the Earth-based facility than in the confines of an ACRV. This may decrease the time necessary for, and the extent of stabilization prior to transport. Either the shuttle or a highly maneuverable ACRV could bring an ill station crewmember to within proximity of an Earth-based treatment facility, eliminating search time and greatly reducing recovery time. If a ballistic or an Apollo-type ACRV is used, the crewmember must be stabilized at the HMF to optimize survivability despite the possibility of prolonged SAR time on Earth. This is due to the less precise landing zones and subsequently increased search times for these designs.

The current U.S. SAR system relies on early rescue and short-term loiter time for victims. Studies derived from military and civilian aircraft mishaps show that the first 12 to 24 hours after an incident are the most critical for the recovery of survivors. Injured survivors have a decreased life expectancy of up to 80% after the first 24 hours. Uninjured survivors also have a rapidly decreased life expectancy after 3 days. Review of the recovery time for 607 survivors of aircraft accidents demonstrates the need to effect a rapid recovery.

Figure 2



Individual survival in the ACRV depends on climatic conditions and the endurance and psychological stability of survivors, the equipment available to them, and the extent of their injuries. All these factors will impact the time an individual will survive in the ACRV as well as the amount of time SAR has to complete its mission.

Disabled crewmembers will have sustained a significant injury or become critically ill prior to departing the station. And, only minimal medical care can be achieved within an ACRV. Our opinion, which is based on the survivability of a crewmember under these circumstances, is that SAR forces should be configured to allow no more than 90 minutes and, optimally, fewer than 60 minutes of loiter time prior to pick up survivors and resume medical care. Also, injured crewmembers should be at a definitive care facility within 120 minutes of landing. Nevertheless, the ACRV should be designed to ensure survivability for uninjured crewmembers for at least 12 hours and optimally 24 hours.

CONSIDERATION 18: A range of potential landing sites must be selected. Optimal medical response must be identified within the confines of these sites.

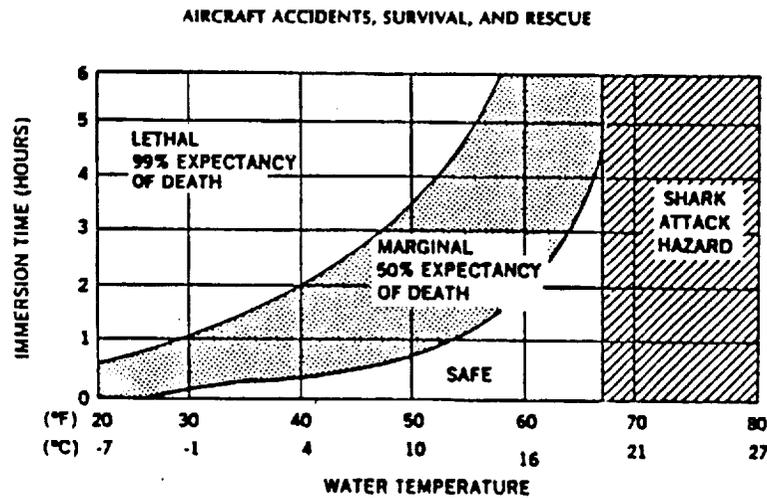
Facts/Comments

To improve the chances of existing recovery forces performing a successful SAR mission, potential landing sites must be selected based on the terrain needed by the escape vehicle, the climatic effects on the human body, and the optimal time-axis intervention. The planned orbital ground track of the station is between 28.5 degrees North and 28.5 degrees South of the Earth's surface. Although it is possible to land anywhere within or near this large area, it is far likelier that, even if immediate evacuation of the station is necessary, any delay in the escape vehicle's retrofire will more precisely select the landing site. The more accurately a landing site can be predetermined, the more effectively recovery forces can be assembled there. Both land and sea contingencies must be considered depending on shuttle availability and the ultimate ACRV design.

A land contingency is likelier if a shuttle rescue or a maneuverable ACRV design is employed. These would allow for precise designation of the landing site, thereby eliminating search time and greatly reducing recovery time compared to a ballistic or an Apollo-derived design. It is unlikely that either of these vehicles would permit a land-based recovery. The impact forces encountered, once these vehicles landed, would be better tolerated in the water. Also, water provides a greater degree of landing safety in a vehicle intended to operate without the assistance of a skilled pilot. Water is a difficult environment for humans to survive in. Although immediate egress from the ACRV by healthy crewmembers may be possible, it is unrealistic to expect significantly ill/injured crewmembers to assist in their own escape or for other crewmembers to be able to safely evacuate patients while on water.

If survivors of a station evacuation must egress from the ACRV prior to arrival of the SAR forces, the time for recovery will be significantly affected by climactic conditions. If the temperature of the water is lower than 34°C, the human body begins to cool. The rate of heat loss is inversely proportional to the temperature of the air and water; and water has a 25 times greater rate of heat exchange than air has at the same temperature. The life expectancy of uninjured survivors immersed in seawater at various temperatures is shown in Figure 3.

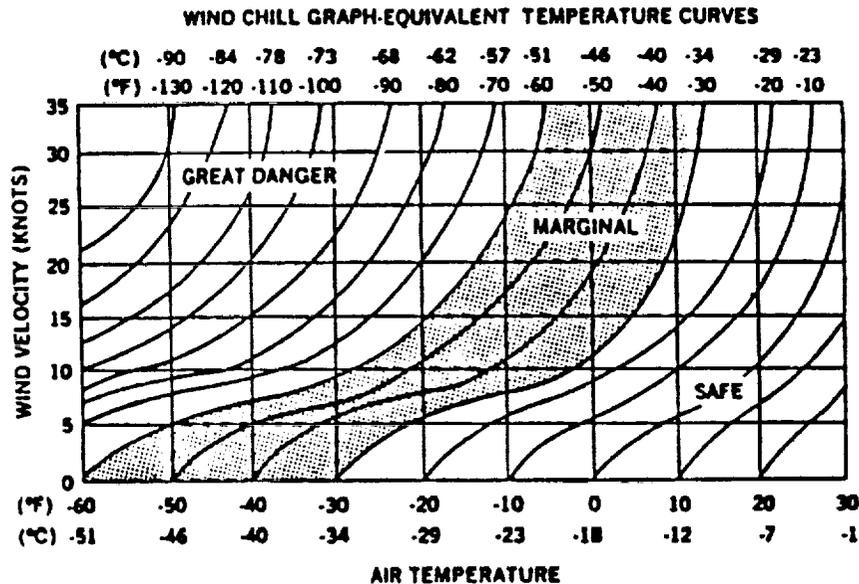
Figure 3



Life expectancy of uninjured survivors immersed in seawater at various temperatures.

Hypothermia may also be accelerated by wind chill. The effect of wind velocity and air temperature is shown in Figure 4.

Figure 4



Effects of wind in reducing the effective air temperature.

Because of these factors, occupants of an ACRV designed to land at sea would have a greater chance of survival if its occupants were kept within the ACRV. The ACRV should provide a suitable internal environment for its occupants while awaiting recovery.

Motion of an ACRV while on water awaiting arrival of SAR forces may hinder crewmembers in their attempts to provide medical assistance for the ill or injured. The experience of Skylab teaches us that at least half of the crew may develop motion sickness. Violent movement of the vehicle in water may make the performance of medical procedures—such as intubation or starting an IV line—impossible. It is expected that crewmembers will be able to provide minimal assistance during loiter time in the water.

Multiple potential sites should be chosen between 28.5 North and 28.5 South longitude. These should be sufficiently varied and geographically separated to encompass the Earth. This would provide for multiple reentry windows on a given day. Additionally, it would provide the opportunity to select the best time on Earth for landing (i.e., dawn) as well as optimal weather conditions. The closer together the sites are, the fewer the cross-range requirements and the smaller the area of coverage at each site.

If a water-based recovery is chosen, potential landing sites should be located in close proximity to onshore facilities. As well as allowing for the evacuation of a crewmember to a tertiary care facility, this choice would enable special personnel and equipment to move quickly into the recovery area. Ideally, the onshore facility would be able to provide a runway for fixed-wing aircraft, too.

CONSIDERATION 19: SAR forces specific for ACRV are to be developed. They should not require significant retraining.

Facts/Comments

The amount of equipment and number of personnel needed for a SAR operation depend on the size of the search area, the degree of illness or injury suffered by crewmembers, the type of terrain that crewmembers must be recovered from, and the survivability of uninjured crewmembers. The final size of the available SAR forces will depend on a cost/benefit analysis; however, some general comments on the composition of these forces should be considered. A SAR system should be capable of rapidly locating station crewmembers, administering emergency care, and extracting and transporting the crew to definitive medical care facilities. The assumption is that SAR forces will be rapidly successful and only short-term survival of fewer than 12 hours will be necessary.

If a ballistic or an Apollo-derived ACRV vehicle is used, a water-based recovery is likely. Although ground tracking forces will probably closely monitor the ACRV's progress to touchdown, satellites should be used for high-altitude surveillance. Operational satellites are today used to monitor the low-power radio distress signal from emergency locator transmitters. These satellites can locate a source to within approximately 5 to 10 miles. Although the size of the recovery zone is expected not to exceed this distance, positioning recovery forces to within 10 miles of the actual landing site may be more difficult.

Fixed-wing aircraft (e.g., helicopters) should be considered for search operations because of their speed and long-range capabilities. In the event they are not immediately available, these aircraft could deploy a pararescue team. The first personnel on the scene would need self-contained breathing apparatus, and they would also need to ensure that no propellant (i.e., hydrazine) has leaked from the ACRV. A pararescue team could render lifesaving and life-sustaining services with a minimum of delay.

In a water-based rescue, helicopters are the most efficient means of rescuing and transporting ACRV personnel. Because of their ability to hover, helicopters provide the only means of evacuation from an ACRV by air. Vertical takeoff and landing aircraft currently under development may be considered in future. Landing zones for the ACRV will need to be within a 150-mile radius of the base station unless midair refueling of helicopters is planned for, or naval vessels are used to bring the helicopters to within the 150-mile range. The use of helicopters to provide medical transport has been extensively evaluated in the military and civilian sectors. Noise, vibration, and turbulence in a helicopter provide a difficult environment in which to perform medical procedures and any needed monitoring. However, personnel trained to work in this environment can safely administer emergency medical care to injured crewmembers while en route to a more definitive care facility. All medical equipment on the helicopter should be compatible with, and complimentary to, that used on the ACRV. Low flight evacuation profiles from the rescue site are preferred to minimize the effect of the decrease in atmospheric pressure and the resultant decrease in oxygen tension associated with increased altitude. Moreover, the volume of space that a gas will occupy increases at higher altitudes. This increase would be deleterious to a patient with air in the cranium, a pneumothorax, an obstructed bowel, or pneumomediastinum. Another possibility would be to airlift the entire ACRV vehicle with the station crewmembers still on board it onto a naval vessel. This would allow for a more controlled environment during extrication. This step would depend on the proximity of a naval vessel to the landing site and the urgency for medical assistance.

U.S. Navy vessels may be required to medically stabilize ill/injured ACRV crewmembers pending evacuation to a tertiary care facility. If a particular medical condition is known to exist prior to departure from the station, the naval vessel may function as an assembly point for specialized personnel and equipment so that more definitive medical care may be rendered on board.

Medical Transport Team

Should a crewmember become ill or be injured while on station, medical assistance must be immediately available. The HMF would be able to provide for routine and minor medical care. But, the facility may only be able to offer supportive care for certain life-threatening illnesses because of limited equipment and the difficulty met in attempting to perform intricate medical procedures in microgravity. A physician crewmember assigned to the space station would be advantageous for the initial diagnosis and treatment of an ill/injured crewmember. If, however, a crewmember sustains a life-threatening injury or illness that is beyond the capability of the HMF and the station medical officer to address, emergency transport to an Earth-based definitive care facility may be necessary.

Transport of an ill/injured crewmember can be broken down into several phases, with a patient encountering different medical assistance with varying medical qualifications at each phase. The appropriate level of training for members of the medical transport team at each phase of the transport must be considered. The time the ill/injured crewmember will spend at each phase of the transport, available space and environmental conditions, and available equipment will impact the level of training necessary for medical attendants at each phase of transport.

CONSIDERATION 20: Qualifications of medical personnel on board the space transport vehicle should be established.

Facts/Comments

Once the decision is made to transport an ill/injured crewmember to an Earth-based treatment facility, the patient should be sufficiently stabilized to maximize the potential for survival despite a transport time of possibly several hours. If a shuttle or a winged/maneuverable ACRV is available, the transport time may be significantly reduced. Since the combination of a short flight time and being able to direct exactly where the landing site will occur decreases the time available to perform extensive medical management, it is unlikely that a physician's skills would be used in flight. After the shuttle or maneuverable ACRV lands, the patient could be quickly extricated and transported to a definitive care facility by pre-positioned Earth-based medical transport crew. Because of this short time interval, only life-sustaining management will be performed on the ill/injured crewmember prior to extrication.

If a ballistic or an Apollo-derived vehicle is used with a water landing, the G profile during reentry would make most medical intervention impossible. Moreover, these vehicles would likely have very limited space available, thereby prohibiting movement during flight. It is unlikely that a physician's skills would be used during flight. After a water landing, there may be as much as a 90-minute loiter time prior to extrication by SAR forces. Because of the limited space and the vehicle's erratic movement in water, only life-sustaining management could be performed. These lifesaving maneuvers include, but are not limited to: airway management including endotracheal intubation, suction, IV medications and fluids, electrocardiogram interpretation, and defibrillation.

Paramedic training ensures that the person administering lifesaving procedures will master these skills as well as 15 training modules, including:

1. Emergency medical technician: his/her role, responsibility, and training
2. Human systems and patient assessment
3. Shock and fluid therapy
4. General pharmacology
5. Respiratory system
6. Cardiovascular systems
7. Central nervous system
8. Soft tissue injuries
9. Musculoskeletal
10. Medical emergencies
11. Obstetrics/gynecology
12. Pediatric and neonatal
13. Management of the emotionally disturbed
14. Extrication/rescue techniques
15. Telemetry and communication

If a physician-crewmember is available on the station, his/her skills may be better used in remaining on station. Since some advanced skills may be necessary after the ACRV lands and while awaiting SAR forces, an ill/injured crewmember should be accompanied by an individual with at least EMT [emergency medical technician]/paramedic qualifications, or by someone who has received a modified version of standard paramedic training.

CONSIDERATION 21: Qualifications of Earth-based medical transport crew should be established.

Facts/Comments

For routine shuttle landings, NASA always has a physician standing by at the landing site. This policy becomes even more critical if an ill/injured crewmember is being returned from the station. Because of NASA's ability to precisely determine a landing site, a physician who is familiar with space adaptation, emergency medicine, flight medicine, ACRV extrication techniques, and the ill/injured crewmember's medical history could easily be at the landing site. If a ballistic or an Apollo-derived ACRV vehicle is used with a water landing, a physician with a similar background could be brought to the landing site by helicopter.

Data can be extrapolated from civilian helicopter emergency medical services. Numerous U.S. studies have demonstrated the benefits of physicians operating in the field. These have concluded that physicians are able to decrease the morbidity and mortality of some transported patients. In their comparison of Level I trauma patients transported by flight nurse/paramedic teams versus flight nurse/physician teams, Baxt and Moody comment that the physician team experienced a significantly lower mortality rate than did the paramedic team⁽¹⁾. In an analysis of 395 flights performed by Metro Life Flight in Cleveland, Ohio, it was shown that, for optimal patient care, a physician was necessary in 25% of flights and that, in 35% of the remaining flights, a physician might have been necessary⁽²⁾. Also, the study found that there had been many flights in which unexpected complications such as loss of airway, hypotension, or cardiopulmonary resuscitation (CPR) were necessary. The study concluded that having a physician present on Metro Life Flight benefited patients.

By having a physician on board a transport helicopter, critical care could be brought to the patient rather than delaying treatment until the ill/injured patient is brought to the receiving hospital. This would be especially vital in the case of a water-based landing where a 30- to 60-minute transport time is highly likely.

Summary

Although a paramedic-crewmember can accompany an injured crewmember during emergency transport from the station, the patient should be met by a team or a physician skilled in both emergency and flight medicine. The physician (or team) would then act as the on-scene medical commander, directing the extrication, immediate treatment, and transport of the ill/injured crewmember.

References

⁽¹⁾ Baxt WG, Moody P, The Impact of a Physician as Part of the Aeromedical Prehospital Team in Patients with Blunt Trauma, JAMA 257(23): 3246-50, 1987.

⁽²⁾ Samuel I, Emerman CL, Effson D, et al. Physician Presence in an Aeromedical Helicopter Emergency Service. Proceedings of the Aeromedical Evacuation Congress, 1985.

Other Considerations

Three unrelated considerations warrant discussion: (1) replacement of the ACRV, (2) medical issues, and (3) the ethics of illness, injury, or death in space.

CONSIDERATION 22: Replacing an ACRV on the space station.

Facts/Comments

An ACRV will most likely be needed when a number of crewmembers remain on the station. Since an ACRV is anticipated to be used only every 4 to 12 years, its return may not be a high priority. Nevertheless, for all the reasons that the ACRV should be in place on the station, it should be replaced as quickly as possible. This could be done with the shuttle or by a pilotless rocket. An important assumption is the existence of a second ACRV and the ability of the original ACRV to be reconditioned to serve as backup for the new ACRV. The apparent need for two ACRVs will be a major factor in estimating costs.

CONSIDERATION 23: A number of medical issues require review and clarity, including health insurance, medical/legal issues, and the need for extended care.

Facts/Comments

Healthcare financing and medical/legal issues have become fairly standardized over the years of crewed spaceflight. In light of the inherent risks associated with prolonged exposure to spaceflight, however, it would be useful to review short- and long-term healthcare financing packages for crewmembers. At the same time, an open stance should be taken toward the possibility of errors in judgment or technological failure during care in the HMF and throughout reentry and recovery. In the present legal and medical climate, it is necessary to consider the risks of medical legal claims and to anticipate their occurrences. Specific insurance policies, waivers, or medical legal opinions are best instituted before they are needed. The status of these discussions should be documented and shared with the crewmembers, their families, and the public via the media.

CONSIDERATION 24: The ethics of and decisions about critical illness/injury and death in space must be discussed.

Facts/Comments

Ethics and decisions surrounding critical illness/injury and death in space must be discussed well in advance of their occurrence. Deliberations should be shared in an appropriate manner with the crewmembers, their families, and the public through the media. With the growth of ethics as a medial specialty, the availability of competent individuals to appropriately analyze these complex issues has never been greater. Questions include:

1. What constitutes a critical, non-transportable disease?
2. What are the criteria for death in space?
3. Who pronounces death, and how is it recorded for medical/legal issues such as time and location?
4. How is the body stored? Is it returned to Earth? Is it "buried" in space? How does this differ if there is a possibly contagious disease?
5. What information is documented concerning the circumstances of death? Are blood tests or other pre-autopsy studies done? If so, which ones?
6. Is an autopsy necessary? If so, how is it arranged? What security measures are necessary?
7. How are these possibilities initially communicated from the space station, ACRV, or landing site to the Mission Control Center?
8. How is this information conveyed to a crewmember's family and to the public via the media?
9. What plans are established to manage the burial of a crewmember?
10. What efforts will be made to support the physical and psychological wellbeing of the living, the families, crewmembers (some of whom may be on the station), and mission specialists?
11. How are "living wills" and similar requests to be handled?

12. Should the ACRV be used to transport the dead?
13. How are the skills of the dead replaced?
14. When is a space station mission stopped and the remaining crew brought back to Earth?

Each of these questions and the many more these questions will generate should be openly discussed and the conclusions publicized. Approaching this difficult task early in the development stages of the station and ACRV will allow appropriate time for analysis, and it will send a clear message of a fully planned mission to all involved.

Summary Consideration

CONSIDERATION 25: Many issues are unknown involving decisions for medical transport, the means of transport, and the physiologic response and outcome of various diseases to reentry and recovery. Nevertheless, they have the same importance and support as those involving the engineering and mechanical aspects of the space station and the ACRV.

Facts/Comments

The space station is, firstly, a human endeavor. The physiology and psychology of medical transport issues thus warrant considerable discussion and expert opinion. The combination of this input with the technical aspects of design and trajectories will optimize the potential for the successful use of an ACRV.

This last consideration is, in many ways, the most important consideration. If it is accepted, the previous 24 considerations and the many others that have not come to mind will fully contribute to a planned and defensible outcome.



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13. ABSTRACT (Maximum 200 words) In developing a permanently crewed space station, the importance of medical care has been continually reaffirmed; and the health maintenance facility (HMF) is an integral component. It has diagnostic, therapeutic, monitoring, and information management capability. It is designed to allow supportive care for: (1) non-life-threatening illnesses; e.g., headache, lacerations; (2) moderate to severe, possibly life-threatening illnesses; e.g., appendicitis, kidney stones; and (3) severe, incapacitating, life-threatening illnesses; e.g., major trauma, toxic exposure. Since the HMF will not have a general surgical capability, the need for emergency escape and recovery methods has been studied. Medical risk assessments have determined that it is impossible to accurately predict the incidence of crewmember illness/injury. A best estimate is 1:3 per work-year, with 1% of these needing an ACRV. For an eight-person crew, this means that one assured crew return vehicle (ACRV) will be used every 4 to 12 years. The ACRV would serve at least three basic objectives as: (1) a crew return if the space shuttle is unavailable; (2) an escape vehicle from a major time-critical space station emergency; and (3) a full or partial crew return vehicle for a medical emergency. The focus of this paper is the third objective for the ACRV.				
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